NORMALIZED CUTS METHOD FOR BIOMEDICAL MRI SEGMENTATION

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Purpose: Biomedical image segmentation is a difficult problem because of many artifacts such as limited image contrast, the presence of noise as well as variations in anatomy and pathology. For that reason, medical image segmentation is often specific to the type of data resulting a variety of methods. Normalized cuts [1] is an efficient segmentation method, robust to local noise and does not need manual initialization, thus it is a good candidate for MRI segmentation. It has also been used for segmentation of the spinal vertebrae [2] and clustering of white matter fiber tracks [3] and gives promising segmentation results.

Methods: The normalized cut algorithm is a graph theoretic method proposed by Shi and Malik. It is based on the representation of an image as a graph where the pixels of the image are the nodes and the edges have weights that represent the similarity between nodes. A measure of similarity can be established considering several features like intensity and distance and weighting probabilistically with the high dimensional Gaussian distribution. Each edge will be represented in the Gram matrix or affinity matrix (W) that represents the nodes and their connections. The graph can be partitioned into two disjoint sets by using the normalized cuts criterion, where the similarity among the nodes in the same set is high and across different sets is low. The normalized cut criterion is obtained by computing the cut cost as a fraction of the total edge connections to all the nodes in the graph and the partition selected is the one that minimizes this cost. The problem of minimizing the normalized cut is NP hard. However, the authors have demostrated that the minimization of this criterion can be approximated as an eigenvector problem of $D^{-1/2}(D-W)D^{-1/2}$ where D is the diagonal matrix that defines the connection of every node to all other nodes by the sum of rows of W, and the eigenvector with the second smallest eigenvalue approximates the optimal normalized cut solution. The computational cost to obtain eigenvectors can be alliviated by making the affinity matrix sparse considering just the local neighbors and using an efficient eigensolver for sparse matrices like Lanczos [1]. However, this limit the range of neighborhood and the effect of the approximation has not been analyzed [4]. Another method that has been used is the Nyström method that gives an approximation of the eigenvectors by solving the problem over a subset of random pixels and subsequently, extending the solution to the entire image [5]. Random sampling has been shown to provide satisfactory results for dense matrices [6] but its perfomance can be further improved by using methods like greedy sampling [7], k-means [8] or the max-min farthest point sampling [9]. After calculating the eigenvectors, the image can be partitioned by minimizing the normalized cut or applying k-means to the k eigenvectors with the smallest eigenvalues. Finally, the last step is to reconstruct the image or subdivide the partitions by checking the stability of the cut [1]. In previous works, normalized cuts has been considered for spinal vertebrae segmentation and white matter fiber tracks clustering obtaining satisfactory results. In the spine segmentation, the authors use normalized cuts with the Nyström approximation and three-dimensional local histograms of brightness as the segmentation feature [2]. In the white matter fiber tracks clustering, authors consider the position, shape and connectivity to create the feature vector and the Gaussian kernel to construct the affinity matrix [3].

Some results using normalized cuts with the Nyström method are shown in Figure 1 and 2. Figure 1 shows an axial slice of the brain where the white and gray matter are segmented in a 4.0 Tesla, MPRAGE T1w image and in the Figure 2, abdominal fat is segmented from a DIXON, 1-5 Tesla lipid image.

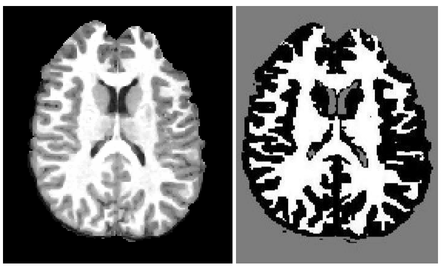

Figure 1. On the left is shown the original image and on the right the segmentation.

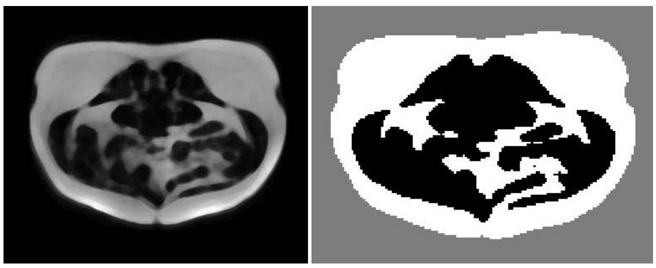

Figure 2. On the left is shown the original image and on the right the segmentation.

Discussion: Normalized cuts can be a good candidate in medical image segmentation due to its efficiency and robustness to noise. It is also a fully automated technique and can be combined with the Nyström method for eigenvector approximation with random spatial sampling. In general, the level sets algorithm has been more widely used for MRI segmentation than normalized cuts. However, normalized cuts has been widely used for other image modalities and has several advantages. Normalized cuts performs a global energy minimization and does not require initialization. Generally, the computation of eigenvectors is more numerically stable than the solution of partial differential equations that the level sets solve. Our future work is to consider spatio-temporal sequences of MRI data for motion segmentation using normalized cuts [10].

References: [1] Shi and Malik. *IEEE Trans. PAMI* 2000,22(8):888-905. [2] Carballido-Gamio et al. *IEEE Trans Med Imaging* 2004,23:36-34. [3] Brun et al. *MICCAI* 2004,368-375. [4] Belongie et al. *ECCV* 2002,531-42. [5] Fowlkes et al. *CVPR* 2001,1:231-38. [6] Fowlkes et al. *TPAMI* 2004,26(2):214-15. [7] Ouimet et at. *AI&Stat* 2005. [8] Zhang et al. *ICML* 2008, 397:1232-1239. [9] Rong et al. *CGI* 2006,172-184. [10] Shi and Malik. *ICCV* 1998,1154-1160.